Biomass of Zooplankton Estimated
by
Acoustical Sensors in the Arabian Sea

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GOALS

The long term goal of our overall research program is the development of data-based models to predict ecological relationships of zooplankton, phytoplankton and the physical environment in the sea.

OBJECTIVES

The overall objective of the work carried out within the scope of this particular contract was to acoustically measure the dynamics of zooplankton and micronekton in the northern Arabian Sea during several seasons. The scientific focus was to examine the impact, if any, of the two annual monsoons that are thought to drive the ecosystem response in the area. This particular project involved the design and construction of two sensors which were then deployed in the Arabian Sea by several of our co-PI's in the ONR ARI on Forced Upper Ocean Dynamics during the time period in which the JGOFS program also focused their efforts on the northern Arabian Sea. This contract involved only the development, calibration and maintenance of the instrumentation.

The data processing, other than that which has been necessary for the purposes of quality assurance, was not included in our original proposal. From the beginning, it has been planned that the data processing, data analysis and the preparation of joint papers with other ONR and JGOFS Arabian Sea investigators would be accomplished in conjunction with several of the Arabian Sea co-PI's and ourselves under a follow-on contractual vehicle. This was deemed a rational approach, since it is much easier to assess the resources that will be required after the quantity of data to be analyzed is known. The funding for a follow-on effort is being allocated from FY97 resources and we are anticipating several analysis efforts as described in the last section of this report.

APPROACH

We designed and constructed two types of sensors for this research project. The first part of the work involved the design and construction of two eight frequency zooplankton sensors for long term mooring. The second part of the work involved the design and construction of a multi-mode, multi-frequency TAPS acoustical sensor for deployment on a SeaSoar towed body. This second acoustical zooplankton sensor system was also designed for independent deployment during CTD casts and during MOCNESS tows.

Technically, the most challenging part of this project was to develop the high power, deep submergence acoustical transducers with operating frequencies appropriate to the detection and sizing of small zooplankton (hundreds of kHz to several MHz). These transducers must maintain their calibrations over a long period, operating without significant degradation to over 500 m and surviving repeated cycling to much greater depths. While we were not funded to do the complete analysis of the data set collected, a preliminary examination indicates that we have been successful in accomplishing this difficult task. This instrument was used during three SeaSoar cruises and two process cruises to measure spatial pattern in zooplankton in relation to features in the physical oceanography of the area.

The moored instruments were intended to measure temporal variations in zooplankton abundance and size at fixed locations. These instruments were deployed, but in one case vibration during shipping caused an IC to fail and in the other, the instrument package flooded during recovery and the data were lost. The flooded instrument was only exposed to sea water for a short period, has been cleaned to prevent long-term corrosion and is repairable.

RESULTS

The SeaSoar TAPS was successfully used during the first and third SeaSoar broad scale surveys by K. Brink's team from WHOI. A void in the

thermister manufacturer's internal potting caused a leak in this instrument during a deep CTD cast during the process cruise between the two SeaSoar surveys, and the instrument was being repaired during the period of the second broad scale survey. Between the SeaSoar broad scale survey cruises and the process cruises, over 1,000,000 independent measurements of volume scattering strengths were collected at 265, 420, 720, 1100, 1850 and 3000 KHz. Each of these measurements consists of an average of scattering levels over 24 pings at each frequency.

During the final process cruise, the data stream became increasingly intermittent, as did the operation of the automatic turn-on, turn-off circuitry. On its return to our laboratory in San Diego, less than a teaspoon of water was found inside the case. This had apparently caused sufficient corrosion to cause the intermittency in the operation of the instrument control circuitry. We were unable to determine the source of the water or whether its presence was due to condensation in the exceptionally humid atmosphere which occurred after the case was opened, or whether it was salt water, present because of a small leak. While we cannot be positive without further analysis of the data, it appears that when data were collected after the corrosion took place, the quality of the data was either obviously good or obviously bad. When the intermittent fault was present, it appears that in most, if not all instances, the instrument simply turned itself off until the fault cleared, probably due to vibration.

The data storage package from the instrument on the Weller mooring was retrieved and returned to San Diego after about six months. The memory contained only data collected during the time the sensor was in the warehouse after it was activated and while on the deck before its deployment. Examination of the package revealed that the single socketed chip, an EEPROM, was partially out of its socket, even though it had been both physically tied and glued into place. When pushed back into place, the system worked. We concluded that the damage was done by shock and vibration during shipping to Oman or during the deployment of the mooring. The extreme heat in the warehouse had apparently caused the glue to melt. The battery and memory for the instrument on the Weller mooring was replaced when the first unit was serviced and the sensor was redeployed for another six months and was retrieved at the end of October 1995. The case flooded during the second recovery process and the data were lost. The sensors on the Ericksen mooring were retrieved in mid-October, 1995 and one battery case had been flooded. All of

Ericksen's current measuring instrumentation on this mooring had been lost, probably due to extreme physical motions caused by the monsoon.

SIGNIFICANCE OF THE DATA COLLECTED

The acoustical data collected in the Arabian Sea is in itself unique. This ocean is badly under-represented in the quantity and quality of both acoustical and biological measurements with respect to other areas. The estimates of zooplankton size-abundance spectra that we anticipate making from the volume scattering measurements will also be unique.

The northern Arabian Sea is one of the most biologically productive and complex areas in the world. When put in the context of the data collected during this year of intensive field experiments by the ONR ARI on Forced Upper Ocean Dynamics, and the concurrent JGOFS, WOCE and GLOBEC efforts, we should gain a great deal of understanding of the spatial and temporal patterns and the underlying causes of these open ocean phenomena. While it is unfortunate that we were not able to successfully retrieve the data from the moored instruments, we anticipate that the huge acoustical data base from the process cruises and the broad scale surveys will allow us to interpolate between discrete biological samples collected as a part of all of these programs. Our results should help place these measurements at discrete locations and times in context and the discrete samples should help us interpret our acoustical data. The spatial patterns of acoustical volume reverberation are in themselves unique and valuable measurements, especially since they are set in the context of numerous other measurements made by other investigators. Hopefully, if funds become available, the result of the next phase of this work, the data processing and analyses, will be a much better understanding of the ecosystem in the northern Indian Ocean, in particular the response of the biota to monsoonal forcing.

SAMPLE OF THE SEASOAR TAPS DATA

We began processing the SeaSoar TAPS data by developing programs to select and display data from interesting subsets of the data bases for each

of the cruises. We illustrate the result for the acoustical data only with a data segment from the September - October 1995 cruise (TTN-051). The cruise track extended in a west by southwest direction from the coast of Oman. Each of the SeaSoar cruises included two "radiator grid" patterns (Fig. 1). We selected a segment from the offshore radiator pattern (RAD2) for our initial analysis of the acoustical data set (centered at approximately 15.6° N, 64.0° E). Data were collected continuously during the to-yo profiling of the SeaSoar towed body, but the tow cable was in the beam on most of the upward "casts". The downward movement segments from these data were extracted, merged with the navigation files, and binned (integrated over 12.5 m depth intervals). The binned data were plotted versus depth as curtain plots on lat/long axes (MATLAB® m-file for the display is courtesy of Peter Wiebe at WHOI).

Patterns in temperature (Fig. 2) reveal a relatively deep thermocline extending to ca 100 m near the SSE border of the area. The thermocline appears to shoal towards the WNW corner of the area occupied. Volume scattering strengths (S_v) are displayed for two of the six TAPS frequencies (Fig. 3 - 420 kHz; Fig. 4 - 3000 kHz) and suggest significant patchiness within this grid. The patterns reveal a correlation of the acoustical scattering with the temperature field, but temperature does not appear to be controlling the small scale patch structure at small scales.

These data also suggest diversity in the size - abundance structure of the patchiness. Note the differences between the scattering at 420 kHz and that at 3000 kHz. For the two frequencies chosen for display here, and for the small sample volumes (ca 0.1 m^3), one would expect that the dominant source of the acoustical scattering at 420 kHz is micronekton and large zooplankton. Smaller zooplankton also contribute to the scattering at the higher frequency. It is notable that the spatial patch structures for the smaller animals appears to be less heterogeneous than that of the larger ones.

Much of the work necessary to organize and merge data sets has now been accomplished under this contract. We have done the necessary data quality control checks and determined our own priorities for further processing and analysis. The next steps are discussed below.

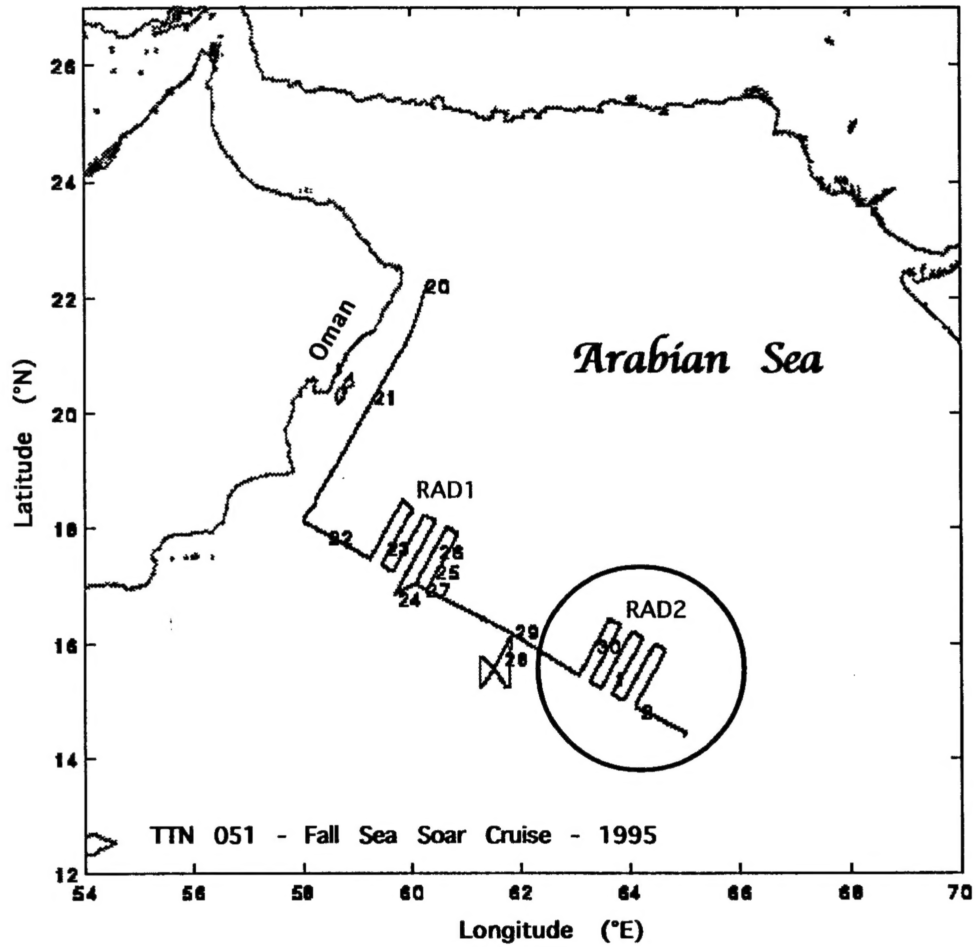

Figure 1: Location of inshore "radiator grid" during SeaSoar cruise (TTN 051) in September - October 1995. This track segment was located west southwest of the Omani coast in the northern Arabian Sea.

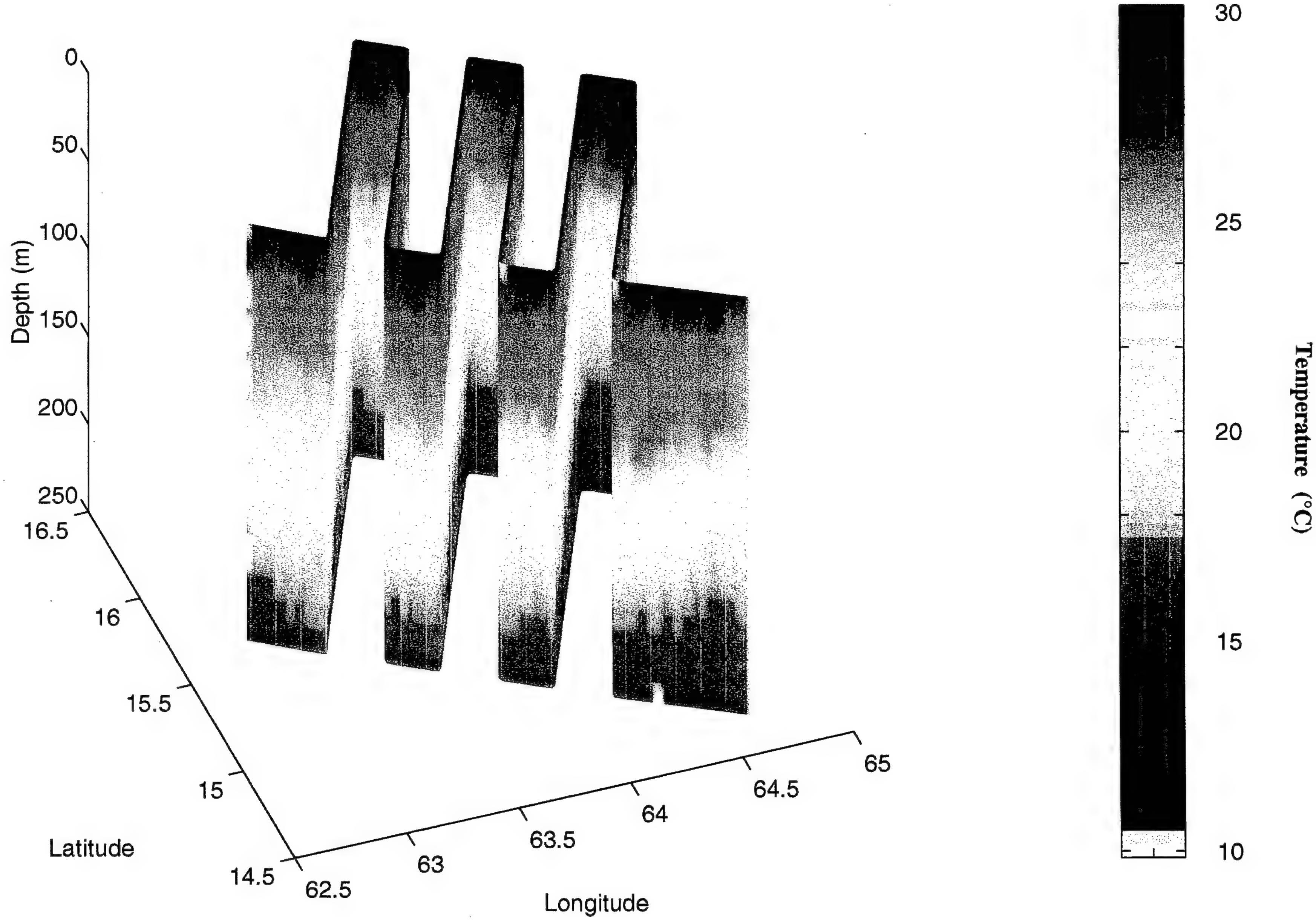

Figure 2: The pattern for water column temperature for a transect in the northern Arabian Sea, along the track illustrated in Fig. 1. Note the shoaling of the mixed layer towards the northwest from its deepest extent in the southeast.

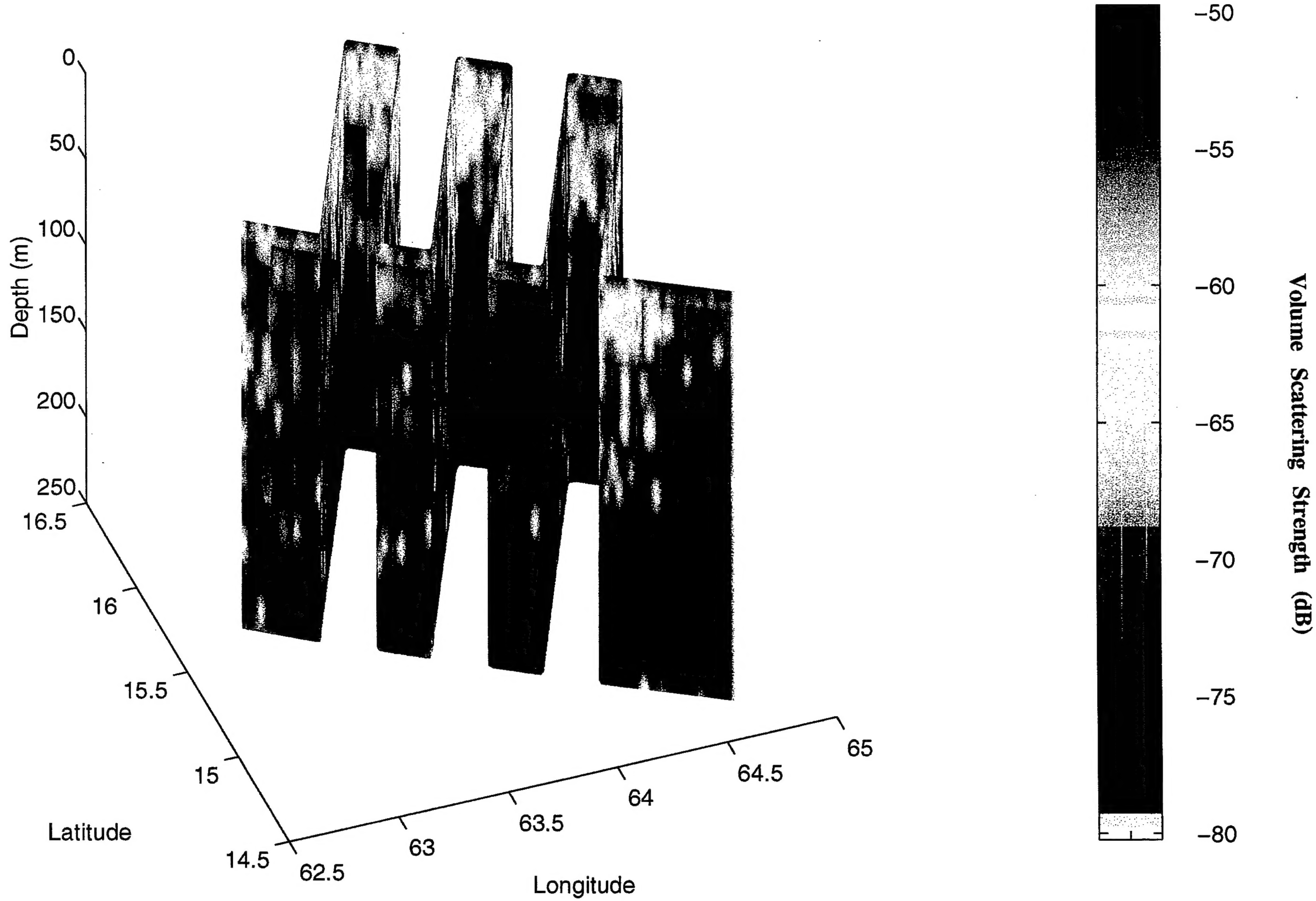

Figure 3: The pattern of acoustical volume scattering strengths at 420 kHz for a transect in the northern Arabian Sea, along the track illustrated in Fig. 1. Note the intensity and scale of the patch structure as well as several apparent coherences with the temperature field as illustrated in Fig. 2.

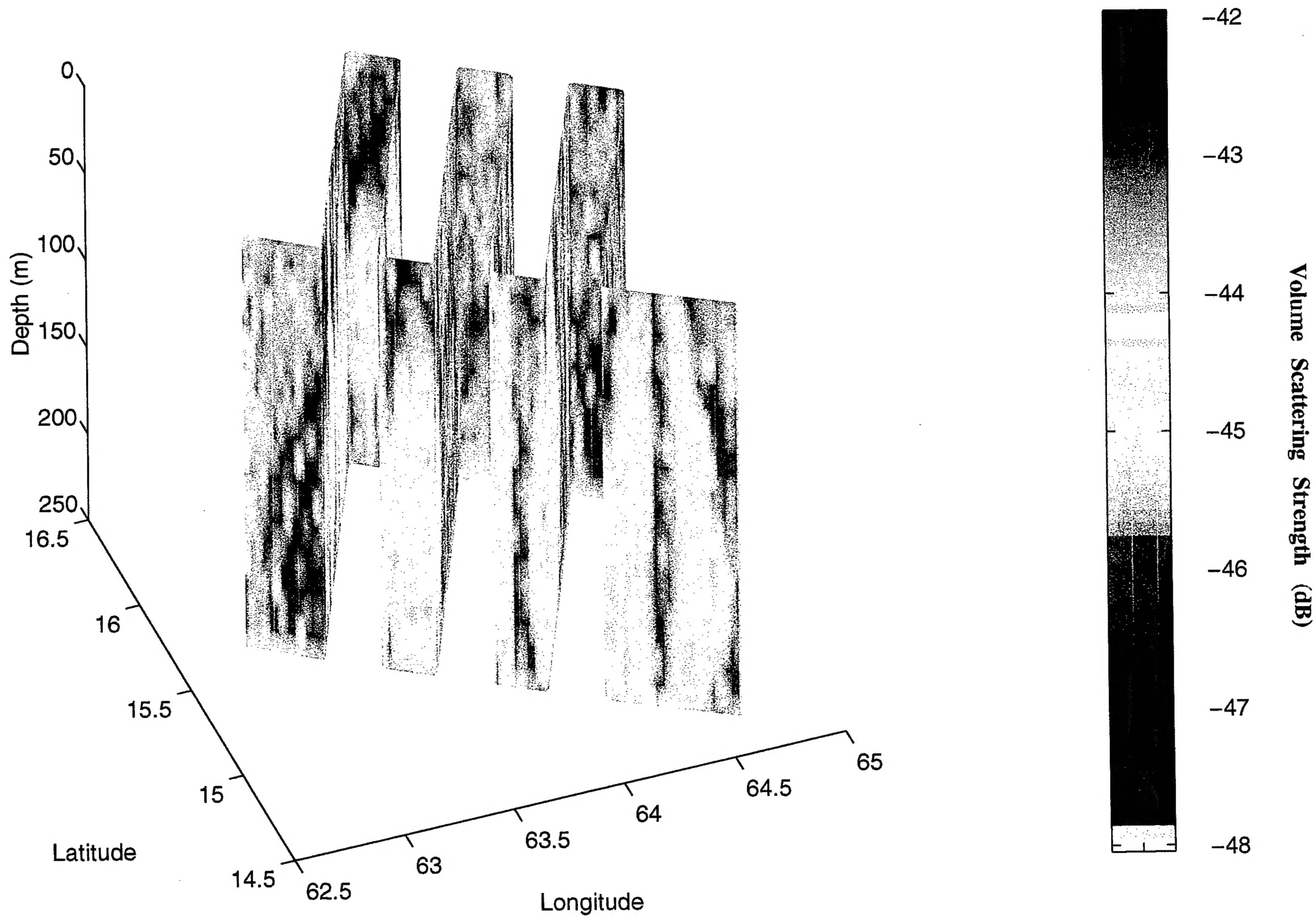

Figure 4: The pattern of acoustical volume scattering strengths at 3000 kHz for a transect in the northern Arabian Sea, along the track illustrated in Fig. 1. The differences between the data at the two frequencies reflect spatial diversity in the size-abundance structure of the acoustical scatterers. For these acoustical frequencies and sampling volume, the likely sound scatterers are micronekton and zooplankton.

PLANS FOR THE FUTURE

We have been discussing processing priorities with cooperating PI's. It is anticipated that processing of the large quantity of data from this program, already over 1,000,000 measurements at each of six frequencies, will be funded in FY 1997. One of our first steps with the new funding will be to transform the acoustical data into estimates of size and abundance of zooplankton and micronekton. This will be a lengthy effort with existing inverse algorithms and computing power. As the process of computing the biomass and size structures proceeds, we will begin discussing details of several cooperative efforts we plan based on the examination of these data with interested co-PIs from different institutions.

One such effort involves the integration of the data sets collected during the process cruises with the TAPS in the CTD cast mode. Mike Roman and Anne Gauzens (Univ. of Md., Horn Point), Karen Wishner (URI), Peter Ortner (NOAA/AOML), and Sharon Smith (U of Miami), all collected both plankton samples and TAPS data during the process cruises. These data can be processed to reveal large scale pattern and low resolution temporal variations near one of the moorings. Additional TAPS data at the mooring site were collected with Dr. Peter Ortner's MOCNESS as were conventional biological samples.

In addition to the ONR and NSF programs discussed above, we worked with Peter Ortner in an attempt to collect data at lower frequencies from several hull mounted transducers on the NOAA ship Baldridge. These frequencies are appropriate to examination of myctophiid and euphausiid distributions, a component of the Indian Ocean ecosystem that is acknowledged as important, but which to our knowledge was not treated elsewhere in any of the science programs which took place in the northern Arabian Sea. These data were collected during several transects into and out of Muscat and include coastal transects as well as transects near both moorings and along track lines occupied by both the SeaSoar group and the US JGOFS process cruises. We did a post cruise calibration on these acoustical sensors when the ship returned to Miami and anticipate proposing to assist Dr. Ortner in the analysis of this potentially valuable data set.

The largest data base (ca 750,000 samples of acoustical volume scattering at each of six frequencies) resulted from the use of the SeaSoar TAPS during the broad scale surveys. We have discussed joint analyses of these data with the WHOI team headed by Ken Brink. We also anticipate analyzing the "radiator grid" sets in a joint effort with John Steele (WHOI). The interest in that particular analysis is in a comparison of patch statistics for the Arabian Sea ecosystem with a data set from the North Sea several years ago. The hypothesis is that the differences in these two ecosystems will be reflected in the measured spatial distributions and patch statistics.

We anticipate that the instruments developed in this project will be refurbished and employed in additional ONR, NSF and NOAA sponsored research programs. We are currently proposing to place at least one of the systems in an array of moorings at our BITS pilot site off Southern California. We have been approached by Dr. Tom Dickey (UCSB) to determine our interest in positioning an instrument on a long term mooring (BATS) in Bermuda. This would complement his optical measurements at the BATS site. There is also interest in deployment of one or more of the moored sensors by NOAA / PMEL on a future mooring in the Bering Sea. We will also be examining ONR's multi-disciplinary research programs for opportunities to cooperate with other ONR PI's in appropriate experimental and field measurement programs.